Preliminary Saturn Atmospheric Density Results from Cassini's Final Plunge

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Plunge characteristics

- Cassini's Rev293 final plunge into Saturn
  - 15-SEP-2017 10:33:17 ET (last tracking data point)
  - +9.22° N latitude, -54.31° E longitude
  - Saturn in Northern Summer, line-of-sight Earth visibility for impact
  - 63.3 mm/s drag ΔV accumulated prior to loss of signal
  - Coherent two-way tracking on 70-m station DSS43
  - Spherical frontal area model equal to 20.5 m^2
  - Fixed drag coefficient C_D=2.1

- Atmospheric Density Model
  - Base densities estimated in layers, lowest layer encompassing loss of signal
  - Layer transitions when accumulated drag acceleration is 10x Doppler noise
  - Scale height computation enforces continuity between layers
  - 100% uncertainty on base densities for estimation

$$\rho = \rho_i \exp\left(\frac{h_i - h}{H_i}\right)$$

$$\boldsymbol{a}_D = -\frac{\rho C_d A V^2}{2m}\hat{\boldsymbol{V}}$$

$$H_i = \frac{h_i - h_{i+1}}{log\left(\rho_{i+1}/\rho_i\right)}$$

Orbit Determination Process

Estimation arc setup

- Data arc:
  - Want to minimize number of parameters in filter
  - Arc focused on plunge, begin near apoapsis of final orbit:
  - 12-SEP-2017 12:00 ET to 15-SEP-2017 12:00 ET
  - Three tracks of 60-sec X/X Doppler prior to experiencing atmosphere
  - One-sec X/X Doppler tracking during atmospheric entry
  - Range data not used

- Force Modeling
  - DE435 planetary ephemeris
  - Correction to SAT389 Saturn system ephemeris from rev271 reconstruction
  - Layered exponential atmosphere for drag modeling
  - Saturn zonal spherical harmonic gravity field J2-J8
  - Impulsive burn models spindown of reaction wheels
  - Spacecraft telemetry for thrusting to counter drag torque
  - Stochastic accelerations estimated for mis-modeled forces

Filter Setup

Filter configuration in JPL's Monte software

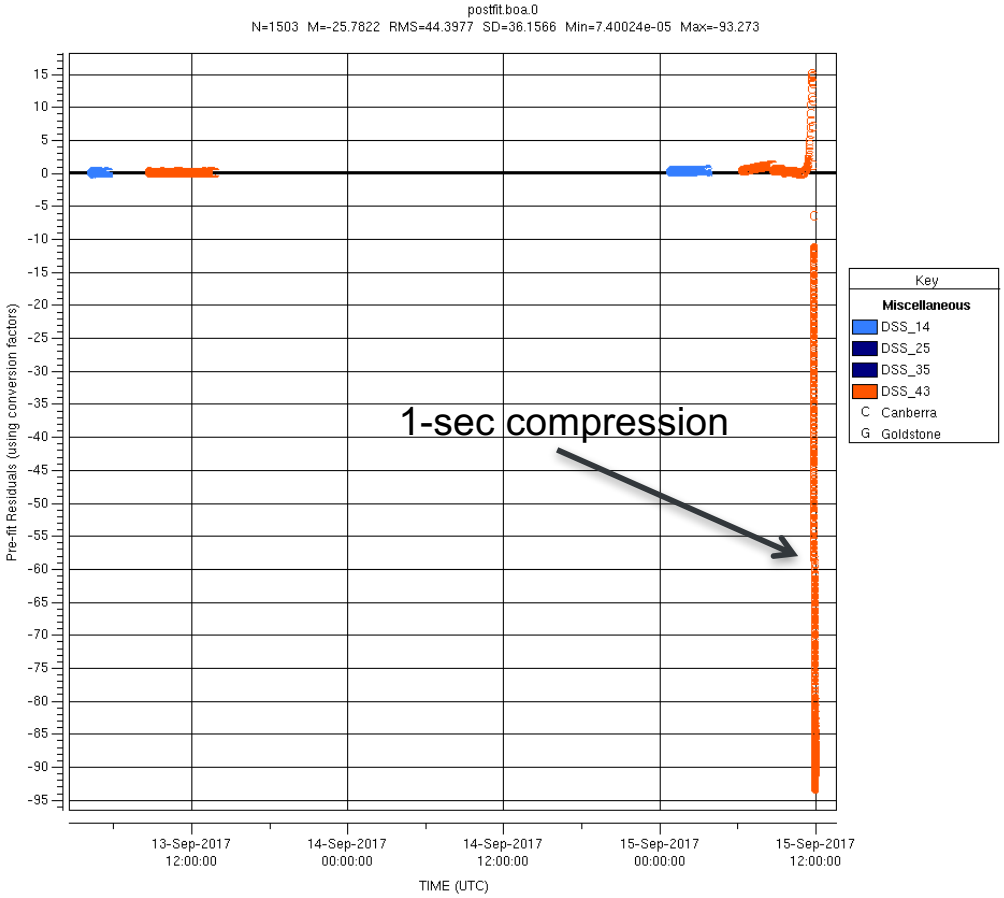
Table 1. Filter parameter setup

Parameter	Unit	Estimated/Considered	a priori σ
Epoch state S/C position - X/Y/Z	km	Estimated	0.4/0.08/0.03
Epoch state S/C velocity - X/Y/Z	mm/s	Estimated	0.53/0.14/0.49
Base Density Layer [0]	kg/km^3	Estimated	1.51E-01
Base Density Layer [1]	kg/km^3	Estimated	2.19E-01
Base Density Layer [2]	kg/km^3	Estimated	2.05E-01
Base Density Layer [3]	kg/km^3	Estimated	1.57E-01
Base Density Layer [4]	kg/km^3	Estimated	8.07E-02
Saturn zonal spherical harmonics	unitless	Estimated	SAT389 updated covariance
Earth polar motion - X/Y	arcsec	Considered	3
UT1 bias	sec	Considered	2.5E-04
DSN station locations	cm/arcsec	Considered	3 / 1
Troposphere path delay - wet/dry	cm	Considered	1/1
Ionosphere path delay - day/night	cm	Considered	55/15
Drag scale factor	unitless	Considered	0.05

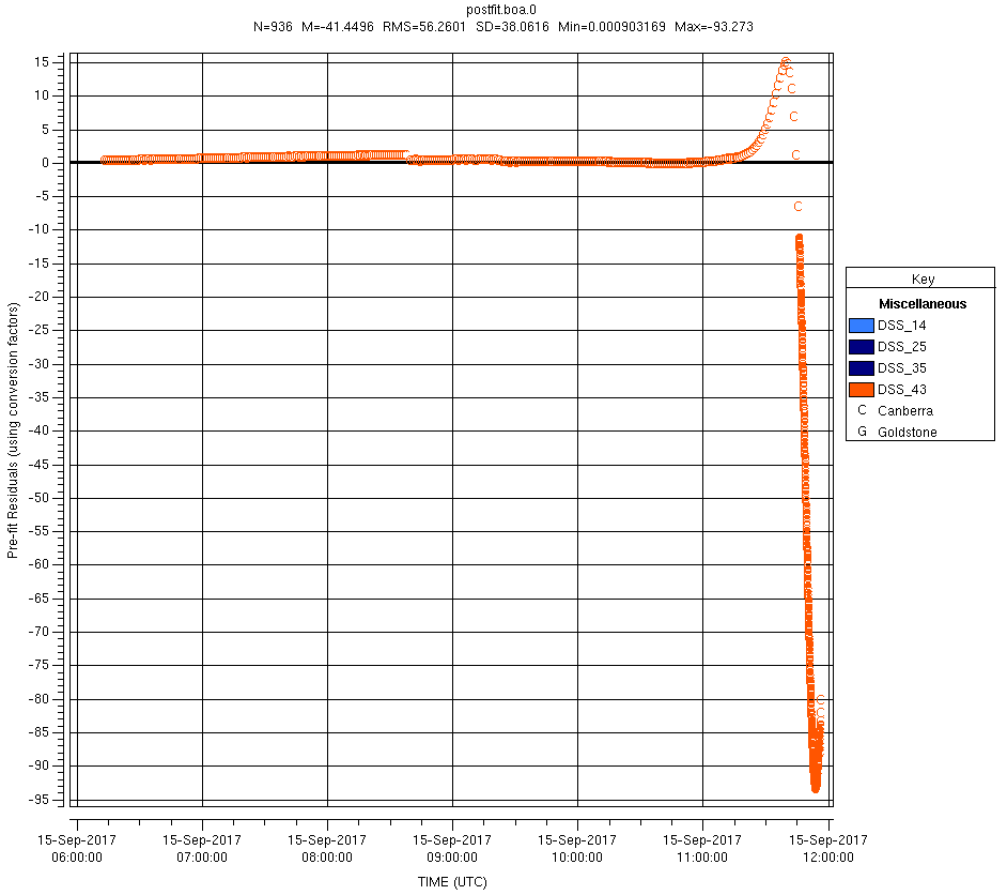
Estimation results

Prefit Doppler residuals for atmospheric entry (mm/sec)

Full arc prefit residuals



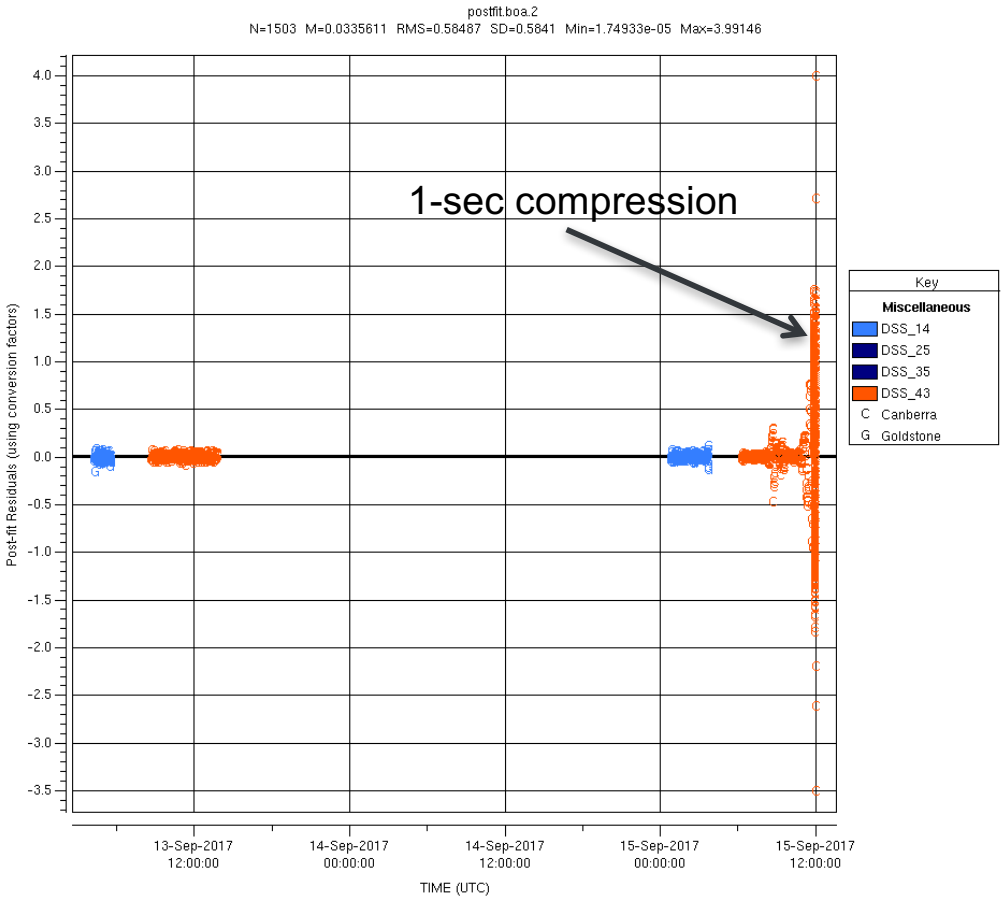
Prefit residuals zoomed on plunge



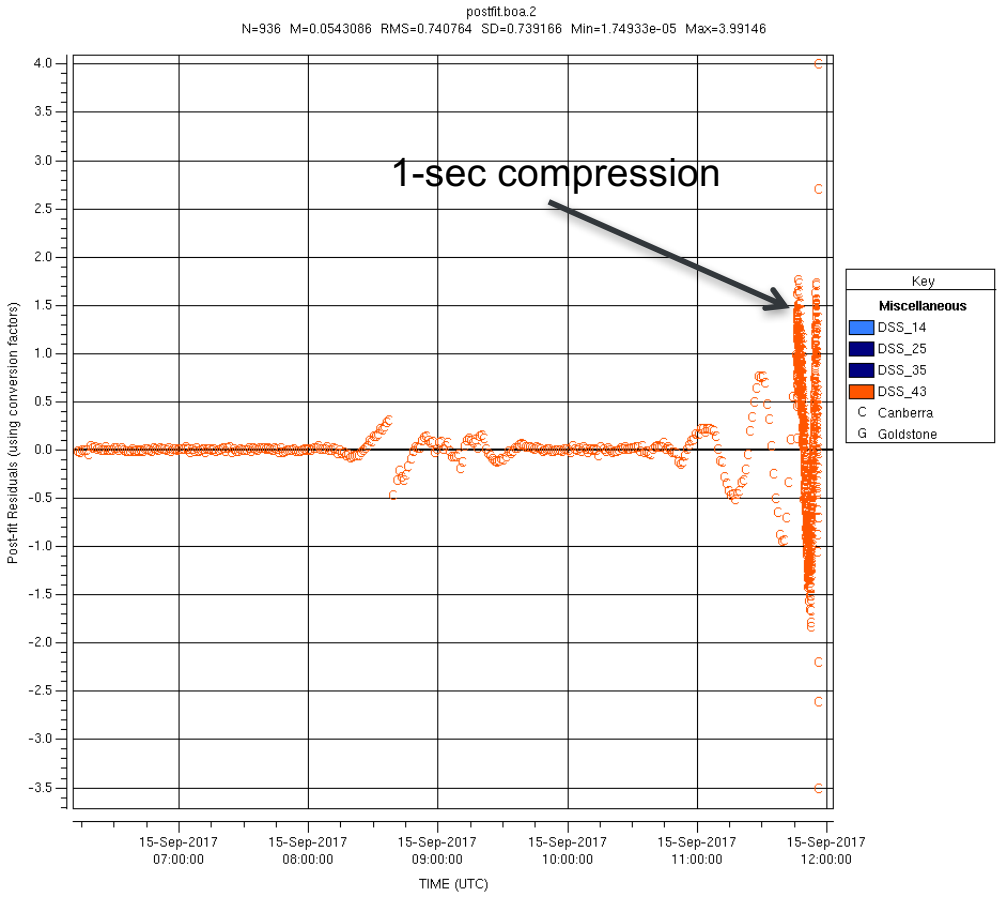
Estimation results

Postfit Doppler residuals for atmospheric entry (mm/sec)

Full arc postfit residuals



Postfit residuals zoomed on plunge



Estimation Results

Base Density Layer Estimates

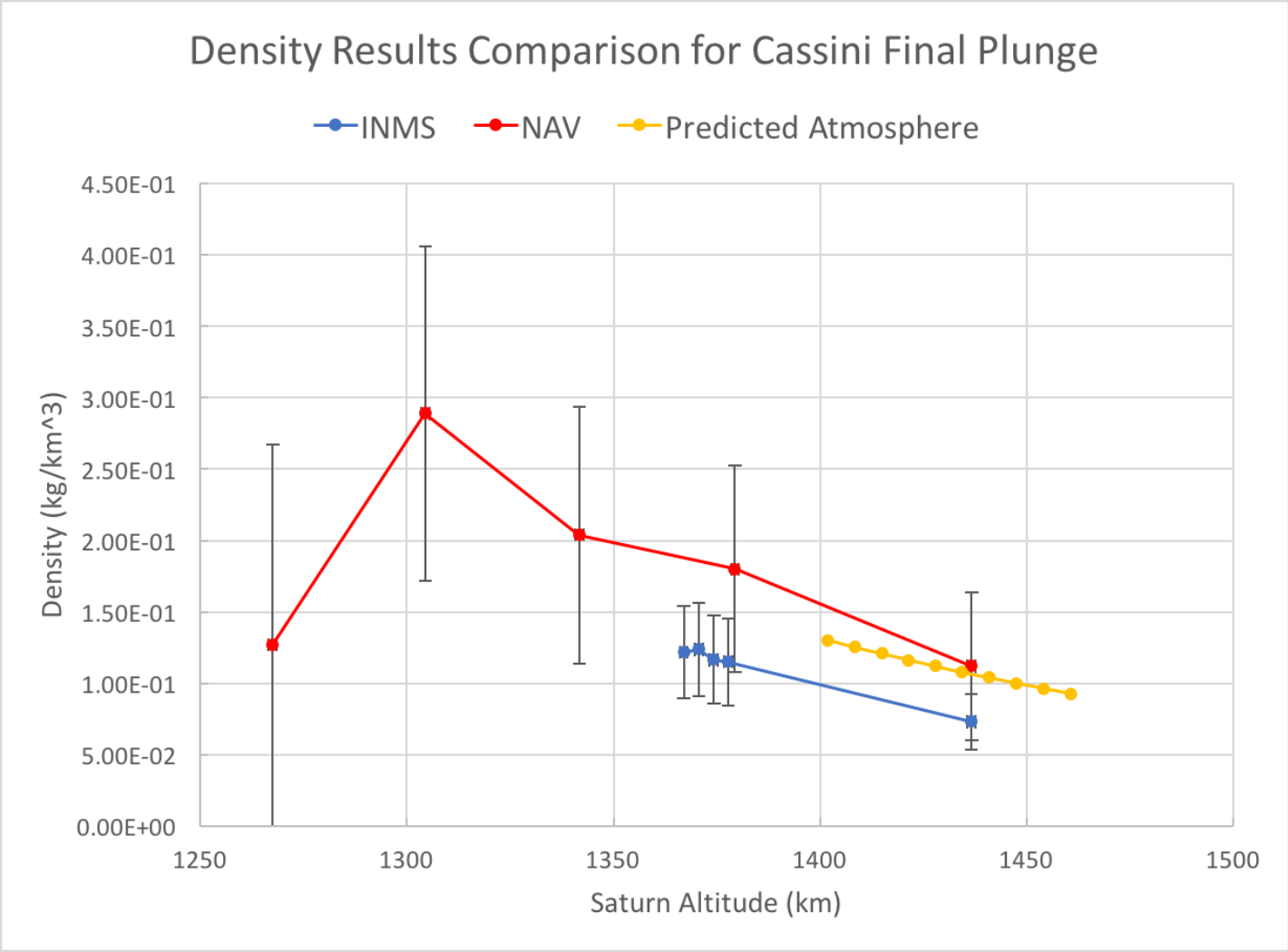
- Uncertainties reflect number of data points in each layer
- Lowest layer under largest perturbations from atmosphere/gravity
- Final Doppler point at 10:33:17 ET (11:55:35 UTC ERT)

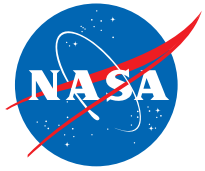
Table 2. Base density layer estimation results

Radius (km)	Base altitude (km)	Base density (kg/km^3)	1σ Uncertainty (kg/km^3)
61376.2	1267.5	1.27E-01	1.40E-01
61407.1	1304.4	2.89E-01	1.17E-01
61438.2	1341.6	2.04E-01	9.00E-02
61469.6	1379.4	1.80E-01	7.23E-02
61517.4	1436.7	1.12E-01	5.20E-02

Comparison to results from other sources

- Error bars plotted as +/- 1σ
- Predicted atmosphere based on experience in last five Saturn revs
- INMS counts converted to mass density assuming H2 atmosphere





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